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14. ABSTRACT

The proposed work has two objectives to improve prediction and assessment capabilities. The first objective is to determine if the generalized equation provided by our new gait mechanics model predicts the metabolic cost of weighted and unweighted walking more accurately than existing generalized equations. Our second objective is to determine how accurately weighted and unweighted walking metabolic rates can be estimated in field settings from simple technologies. Metabolic rates will be measured from expired gases. The timing of each walking stride, as well as its subcomponents (i.e. the contact and leg swing portions) will be determined from video. In addition, the periods of muscular activity responsible for executing the movements of the walking stride will be also assessed from electrical activity using surface electrodes attached to the skin above target muscles. The forces that subjects apply to the ground during locomotion may be measured from either a force plate or force sensors built into a treadmill. Finally, heart rate monitors to measure heart beat frequency, miniature motion sensors mounted to the shoe or other parts of the body to measure movement speeds and rates may also be utilized.

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Locomotion, gait, metabolism, body size, load carriage

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INTRODUCTION

The proposed work has two objectives coordinated to fulfill the overall objective of improving quantitative estimates of locomotor metabolism and activity in field settings. The objective of the first portion of the experimental work is to develop generalized equations that relate height, weight and speed to the metabolic rates incurred during walking. Fulfilling this objective will involve assessing whether the generalized equations provided by our new gait mechanics model will predict the metabolic cost of weighted and unweighted walking more accurately than existing generalized equations under controlled conditions. Our second objective is to determine how accurately weighted and unweighted walking metabolic rates can be estimated in field settings using simple, inexpensive wearable technologies.

Metabolic rates will be measured from expired gases. The timing of each walking stride, as well as its subcomponents (i.e. the contact and leg swing portions) will be determined from video and/or ground reaction force data. In addition, the periods of muscular activity responsible for executing the movements of the walking stride may be assessed from electrical activity using surface electrodes attached to the skin above target muscles. The forces that subjects apply to the ground during locomotion may be measured from either a force plate or force sensors built into a treadmill. Finally, miniature motion sensors and geolocation devices mounted to the shoe or other parts of the body to measure movement speeds and rates will also be utilized. Field trials will be conducted using lightweight, portable indirect calorimeters. Subjects will walk both with and without weighted backpacks during both the laboratory and field trials.

BODY:

Note: through coordination with TATRC and the program officer, the intervals for our quarterly reports deviated slightly from the original reporting schedule (both earlier and later). Therefore, not all reporting periods below were of 3 months, or true quarterly durations.

<u>November 2010 through February 2011:</u>

Human subjects approval of our protocol was granted in November of 2010. During the first quarter, we successfully recruited 18 subjects and enrolled 11 subjects in the study. Five completed

the full experimental protocol for our aerobic fitness objective which includes measurements for resting and walking metabolic rates in duplicate.

The stature-based metabolic model performed very well for the five subjects tested during this time, accounting for > 97% of the variability in walking metabolic rates between individuals and across speeds per the illustration in Figure 1.

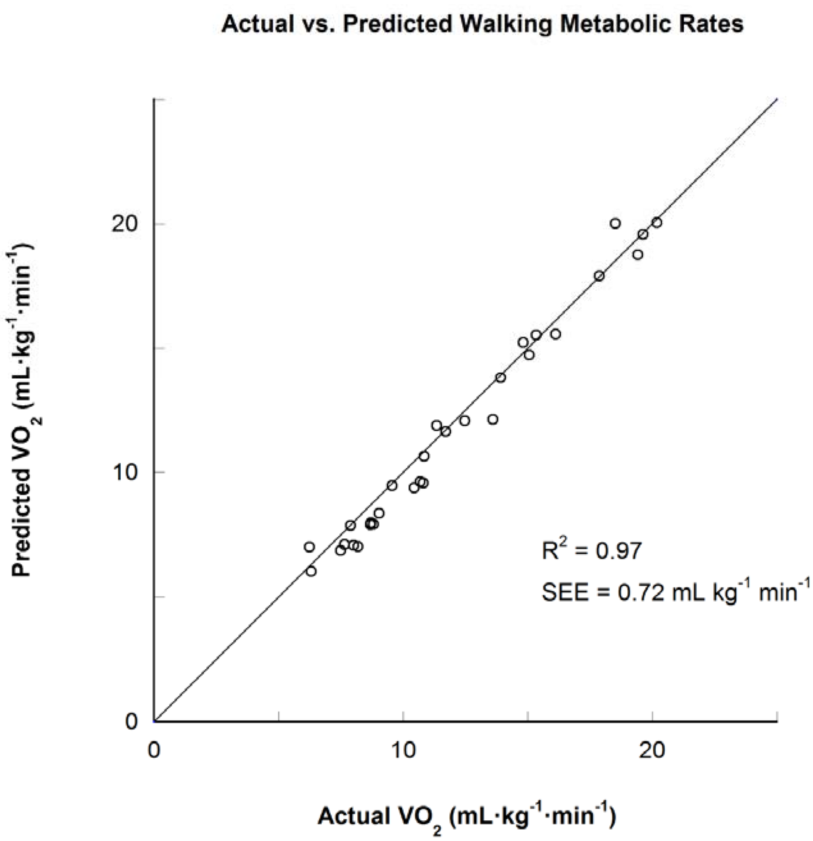

Figure 1. The measured rates of oxygen uptake of 5 subjects at six different walking speeds from 0.4 to 1.9 meters per second closely matched those predicted by our stature-based model.

Our aerobic fitness model relies directly on the accuracy of the rates of oxygen uptake and metabolism predicted by the model. Accordingly, our results thus far are quite encouraging. Additionally, the coefficients and exponents in the model agree almost exactly with those previously derived on a much larger group of subjects, thereby supporting the general validity of the variables in the model and their stability across independent groups of subjects.

At this point, we did not yet have sufficient data available to evaluate the accuracy with which we will be able to predict the aerobic fitness of our subjects as our number of subjects tested was too small to provide any meaningful evaluation.

In this quarter we also improved and refined our techniques for evaluating walking kinematic variables in the laboratory such as stride time, contact time, stride length and duty factor. The primary change has been using Vista software program that allows us to both store and analyze video files electronically. This has greatly enhanced our ability to organize, store and retrieve the data.

We continued to work on the second manuscript of our new walking model that is distinct from previous models in that stature is included as a predictor. The new paper will further develop the applications of the model by extending predictive relationships to the complete range of walking speeds. The new algorithms predict walking metabolic rates from height, weight and walking speed.

Since the last report and the media features reported at that time, we did two additional features for Nippon Television which is one of the national networks an Japan and a radio interview for the Canadian Broadcasting System's "Quirks and Quarks" weekly science radio show which is broadcast throughout Canada.

February 2011 through April 2011:

Ten additional subjects were tested during this time. This brings the total number of subjects who completed our combined walking metabolism and walking aerobic fitness test protocols (requiring three laboratory testing sessions) to 15. We also recruited an additional 10 subjects to participate.

The stature-based metabolic model continued to perform well with the ten additional subjects, accounting for 90% of the variability in walking metabolic rates between individuals and across speeds per the illustration in Figure 2.

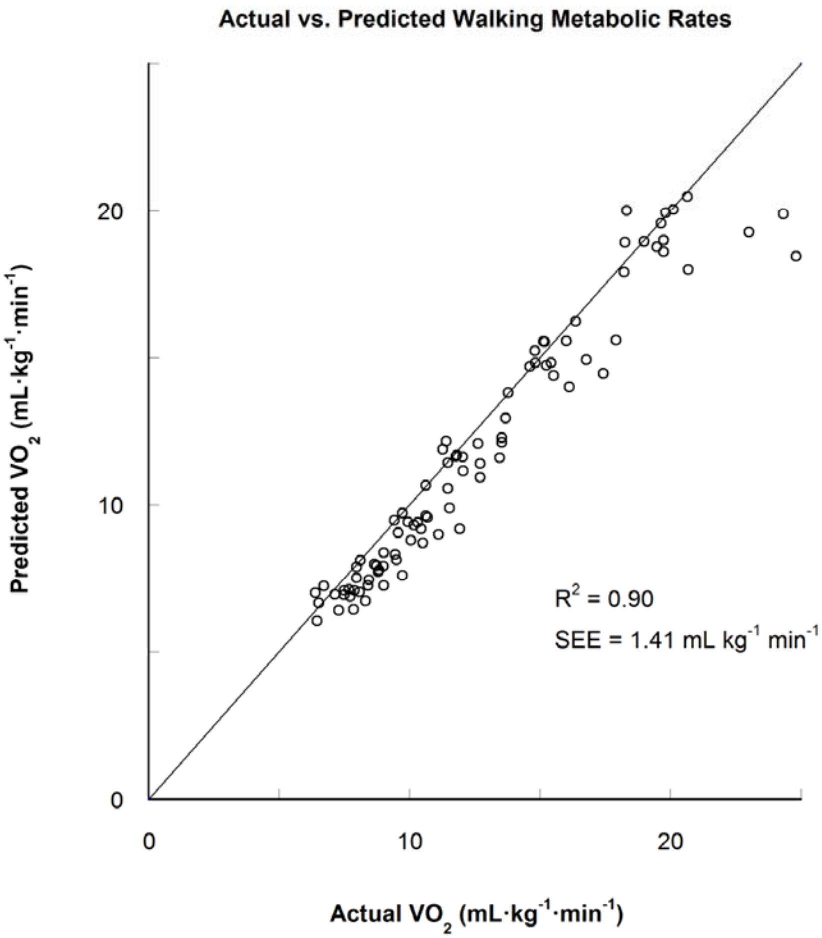

Figure 2. The agreement between measured and predicted rates of oxygen uptake (n=15 subjects) at six different walking speeds from 0.4 to 1.9 meters per second.

Our aerobic fitness model relies directly on the accuracy of the rates of oxygen uptake and metabolism predicted by the model. Accordingly, our results thus far are reasonably encouraging.

Using sub-maximal heart rates and the walking metabolic rates predicted by our stature-based model in combination with the algorithms we have formulated thus far has enabled us to predict the maximal aerobic power of a set of 29 subjects previously tested to within less than 5% using a single steady-state heart rate value from a moderate to fast walking speed. However, our best-fit algorithms do not predict maximal aerobic power with equivalent accuracy across the full range of aerobic fitness values at this point. So, we plan to continue to refine our

algorithms to address this going forward. However, we do feel that we may currently be at a level of agreement that warrants moving forward with the intellectual property utilized for our walking aerobic fitness index technique. We will seek the consultation of our USARIEM and TATRC colleagues.

We have continued to work on two manuscripts supported by this award, one on performance and fatigue during brief, high-intensity exercise and a second on our new stature-based model of walking metabolism. The walking paper in progress will further develop the applications of our stature-based model by extending predictive relationships to the complete range of walking speeds per Figure 2 above. The new algorithms predict walking metabolic rates from height, weight and walking speed.

<u>April 2011 through July 2011:</u>

Twelve additional subjects were tested during this time for a total of 27 subjects who completed our combined walking metabolism and walking aerobic fitness test protocols (requiring three laboratory testing sessions). In addition, three subjects were in the midst of testing and roughly 6 more were enrolled at the conclusion of this quarter.

The stature-based metabolic model continued to perform well with 27 subjects, accounting for 93% of the variability in walking metabolic rates between individuals and across speeds per the illustration in Figure 3.

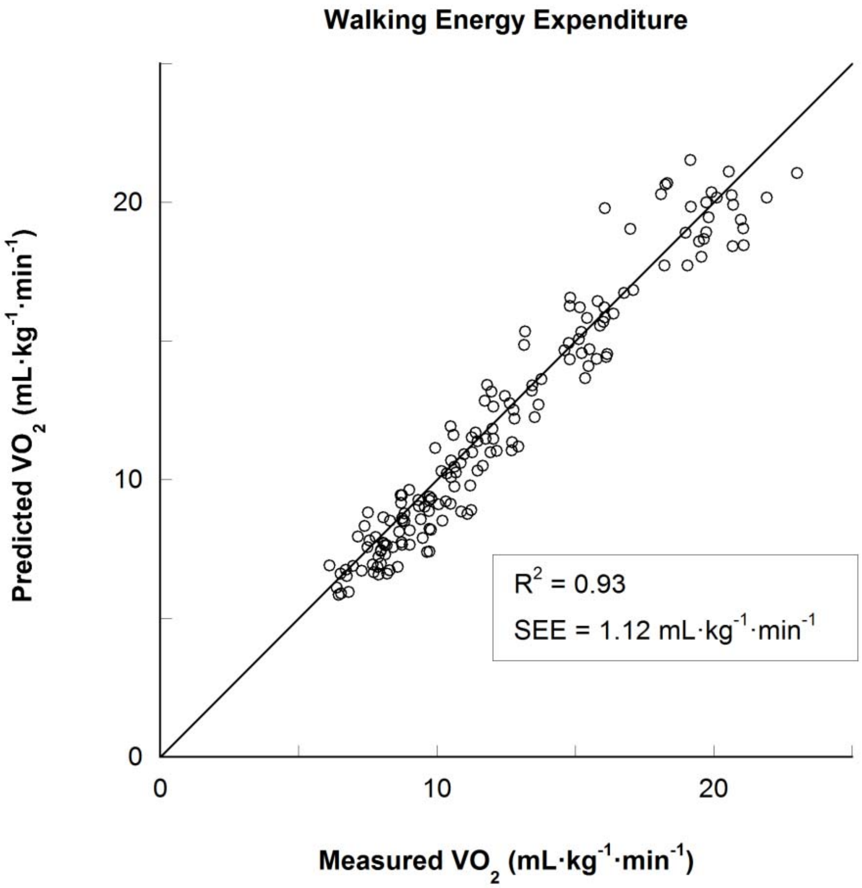

Figure 3. The agreement between measured and predicted rates of oxygen uptake (n=27 subjects) at six different treadmill walking speeds from 0.4 to 1.9 meters per second.

During this quarter, we began testing our walking model in overground outdoor trials as the next logical step toward transitioning our model for general field use. Four subjects completed a three-speed protocol on level asphalt with metabolic measurements being acquired using the Douglas bag technique. The agreement of the treadmill data from the laboratory and the over-ground data for these subjects is illustrated in Figure 4 below.

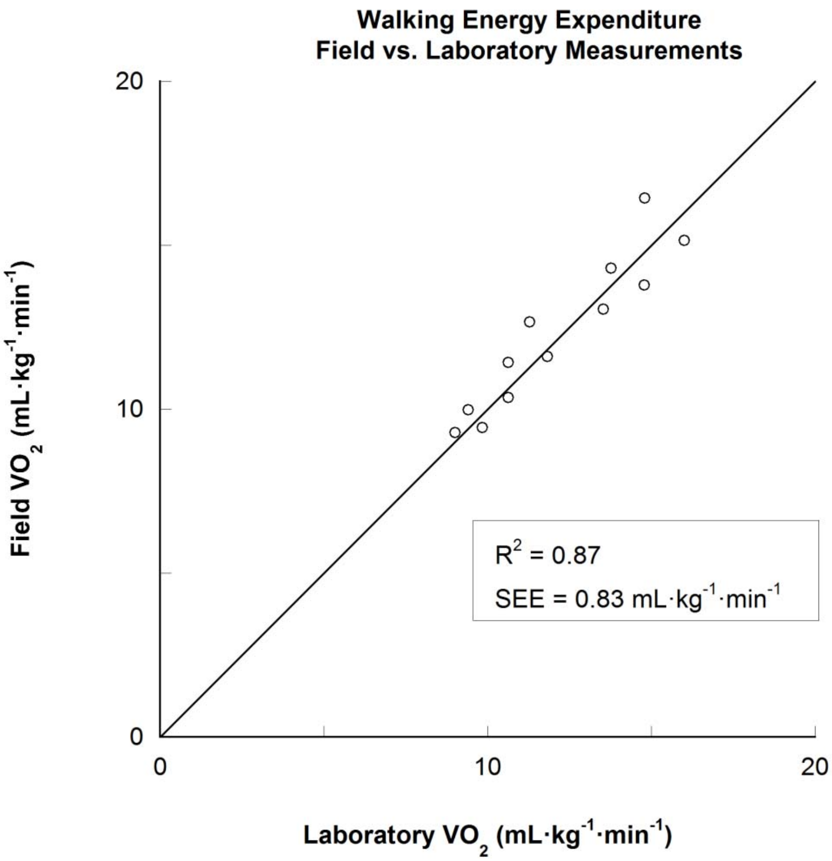

Figure 4. The agreement between treadmill and over-ground rates of oxygen uptake (n=4 subjects) at three walking speeds: 1.0, 1.3 and 1.6 meters per second.

The predictions provided by our stature-based model on the over-ground trails thus far completed appear below in Figure 5.

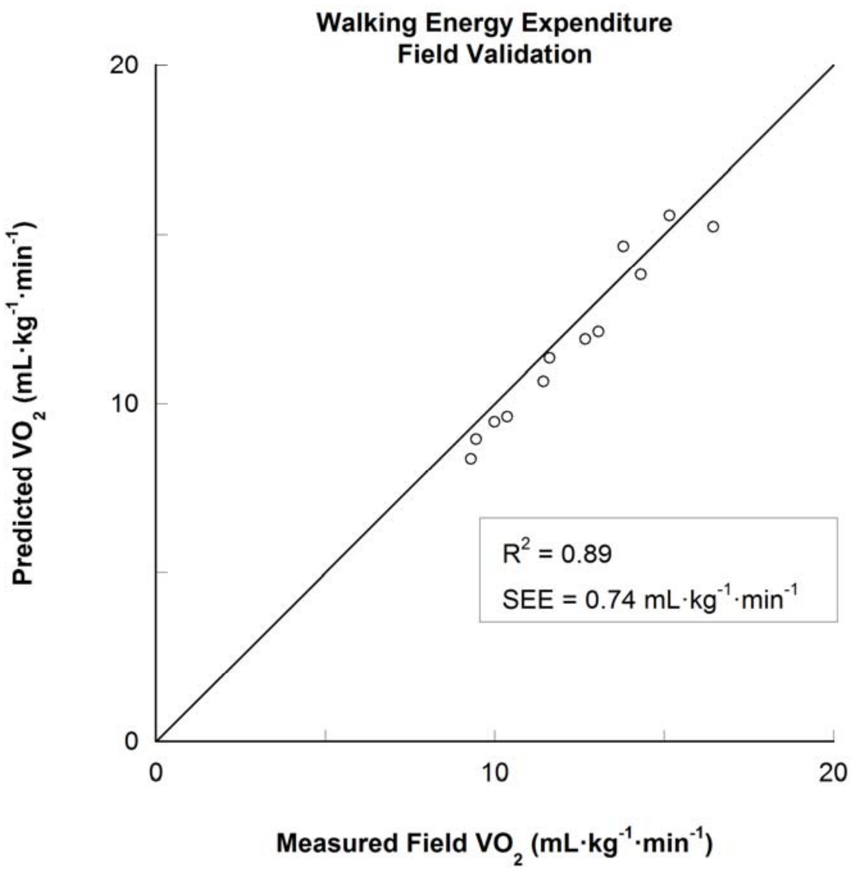

Figure 5. The agreement between measured rates of oxygen uptake (n=4 subjects) during over-ground walking at 1.0, 1.3 and 1.6 meters per second vs. the rates predicted by our stature-based model.

In addition, all 27 subjects tested for the further development of our stature-based model of walking energy expenditure also completed resting and maximal metabolic rate tests. We have thus far developed a two-step algorithm to estimate maximal aerobic power from submaximal heart rates. Our current predictive accuracy is roughly 10%. However, considerable work on algorithm development remains.

<u>July 2011 through October 2011:</u>

Twelve additional subjects were tested during this time for a total of 39 subjects. Thirty-four completed our combined walking metabolism and walking aerobic fitness test protocols (requiring three laboratory testing sessions) and 5 completed a shortened version of the protocol.

The stature-based metabolic model continued to perform well with 34 subjects, accounting for 93% of the variability in walking metabolic rates between individuals and across speeds per the illustration in Figure 6 (with an SEE of 1.08 mls•kg^{-1}•min^{-1}) .

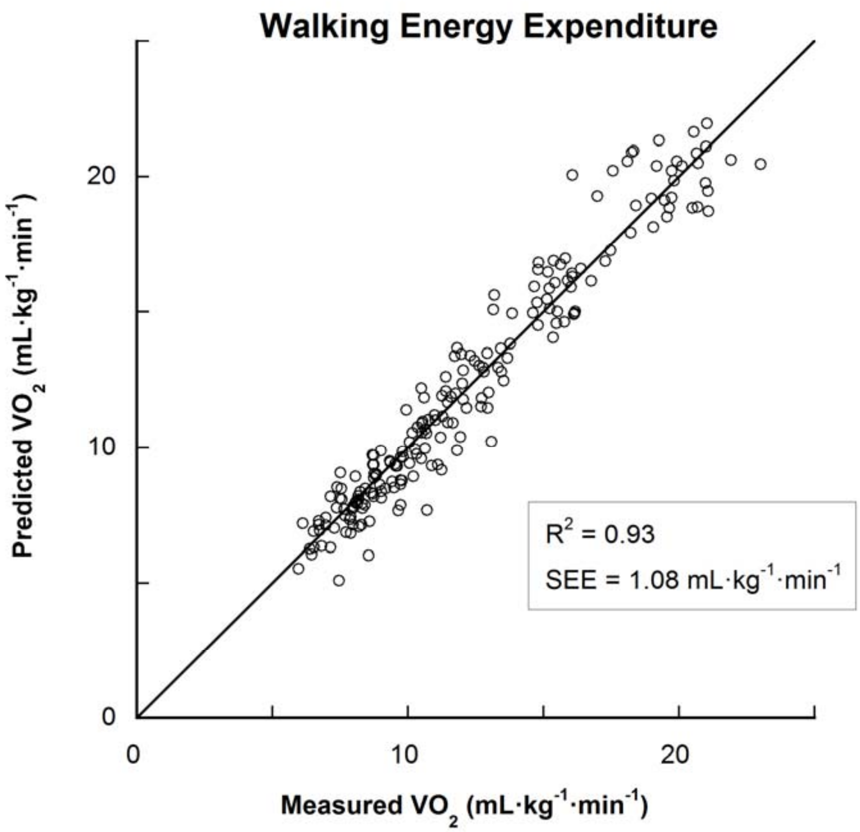

Figure 6. The agreement between measured and predicted rates of oxygen uptake (n=34 subjects) at six different treadmill walking speeds from 0.4 to 1.9 meters per second.

We continued testing our walking model in overground outdoor trials and 8 additional subjects were tested. Twelve subjects completed a three-speed protocol on level asphalt with metabolic measurements being acquired using the Douglas bag technique. The agreement of the treadmill data from the laboratory and the over-ground data for these subjects is illustrated in Figure 7 below.

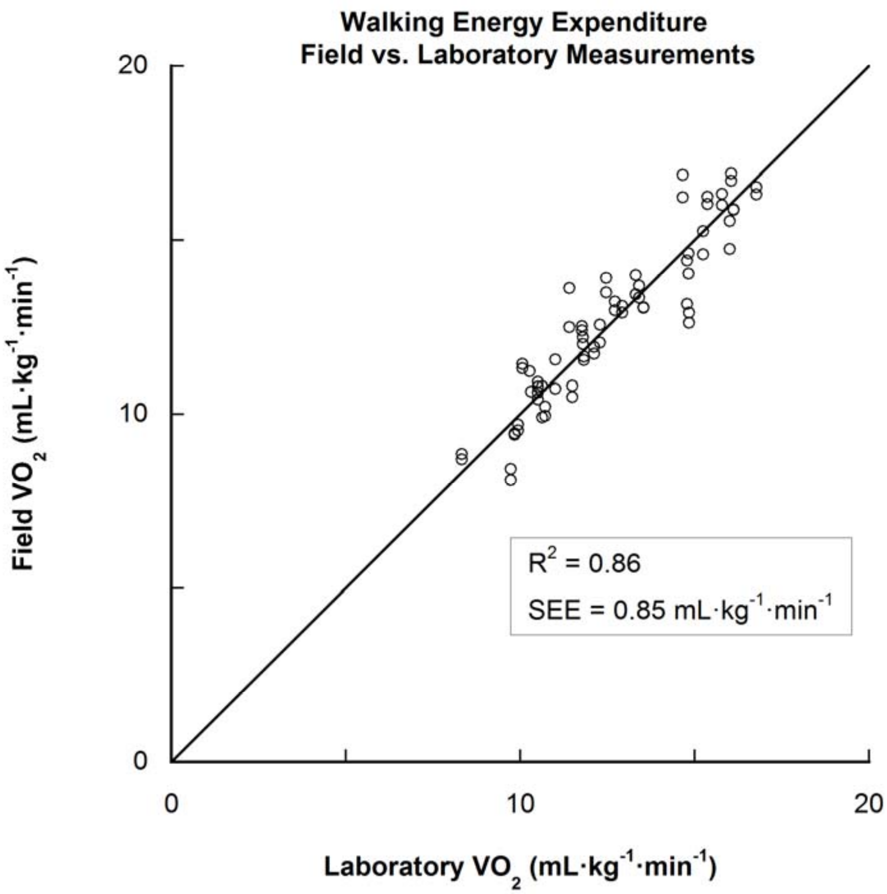

Figure 7. The agreement between treadmill and over-ground rates of oxygen uptake (n=12 subjects) at three walking speeds: 1.0, 1.3 and 1.6 meters per second.

The predictions provided by our stature-based model on the over-ground trials thus far completed appear below in Figure 8.

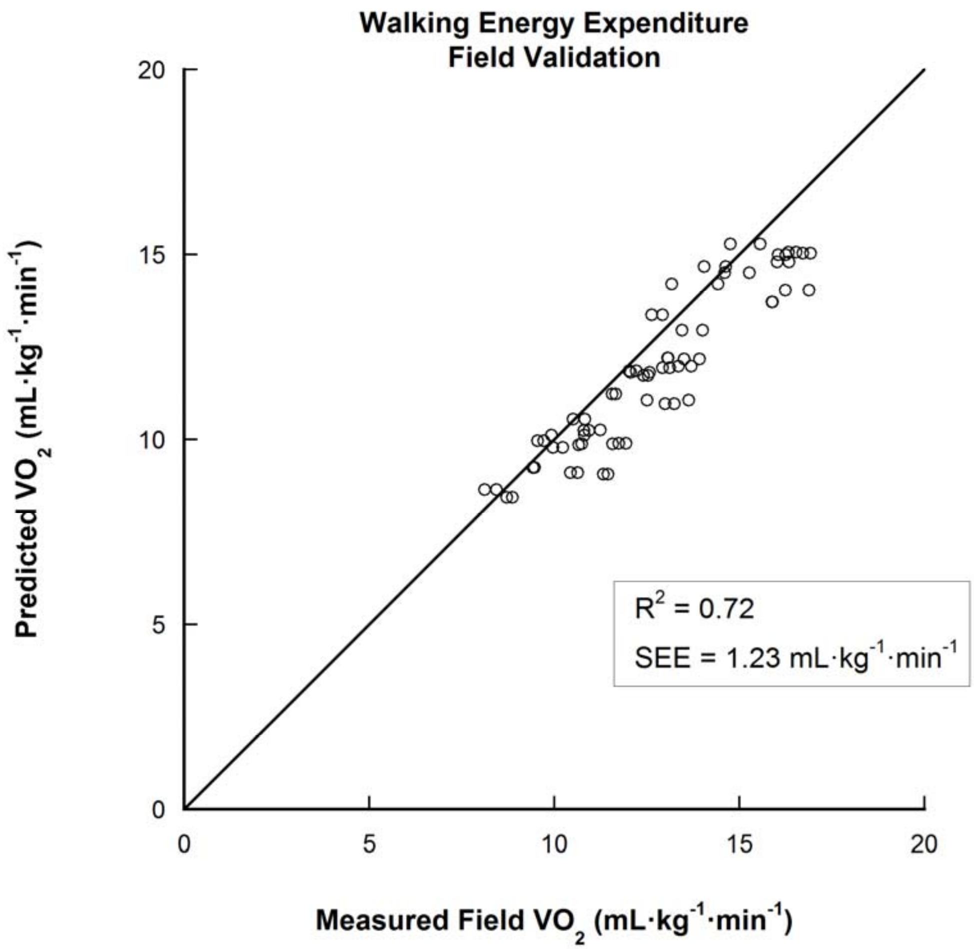

Figure 8. The agreement between measured rates of oxygen uptake (n=12 subjects) during over-ground walking at 1.0, 1.3 and 1.6 meters per second vs. the rates predicted by our stature-based model.

In addition, 38 of the 39 subjects who were tested for the further development of our stature-based model of walking energy expenditure also completed maximal metabolic rate tests. We have thus far developed a two-step algorithm to estimate maximal aerobic power from submaximal heart rates. Within the last quarter, we have focused efforts heavily on the analytics needed to develop and refine the algorithm involved in the two-step process that would maximize predictive accuracy. These efforts have resulted in significant advances. Our new algorithms predict maximal aerobic power with an average accuracy between 7.0 and 8.0% for fully independent predictions on the 38 individuals tested (VO_{2max} range = 19 to 67 mls•kg^{-1}•min^{-1}). Our

average absolute error for these predictions currently stands 3.73 mls•kg^{-1}•min^{-1}, and our working SEE is 4.9 mls•kg^{-1}•min^{-1}.

We plan to increase the number of subjects tested and specifically recruit individuals likely to be at the high and low fit extremes of our healthy population. We put in, and were granted, a request to expand the number of subjects tested to meet this objective.

KEY RESEARCH ACCOMPLISHMENTS (Nov–Feb):

• Subject recruitment and testing began in November of 2010.

• Eighteen subjects were recruited, eleven subjects were enrolled, and five completed the testing on the aerobic fitness objective of our protocol.

• A new system of video storage and analysis was implemented using Vista software.

KEY RESEARCH ACCOMPLISHMENTS (Feb-April):

• Subject recruitment was expanded to 25 subjects; 15 subjects completed our three-session walking model/walking aerobic fitness index testing.

• Our preliminary walking index of aerobic fitness was providing a best-fit algorithm that estimates measured values for maximal aerobic power to within less than 5% on average.

KEY RESEARCH ACCOMPLISHMENTS (April-July):

• Subject recruitment was expanded to 35 subjects; 27 subjects completed our three-session walking model/walking aerobic fitness index testing.

• Field testing of our stature-based walking model began.

• Our walking index of aerobic fitness algorithms moved into rapid development as we acquired the data needed for this purpose.

KEY RESEARCH ACCOMPLISHMENTS (July-Oct):

• Subject recruitment and testing was expanded to 39 subjects; 34 completed our three-session walking model/walking testing, 5

completed a shortened walking protocol and 38 of the 39 completed testing for maximal aerobic power.

- Field testing of our stature-based walking model was expanded from the 4 subjects tested in the previous quarter to a total of 15 that completed the outdoor over-ground measurement protocol.

- We requested and obtained one of two required permissions from the IRB at SMU to add a 2nd outdoor validation on a grass field.

- Our walking index of aerobic fitness algorithms were refined in several ways that more successfully used simple and readily available inputs such as height, weight, walking speed and heart rate to predict maximal aerobic power.

REPORTABLE OUTCOMES (Nov-Feb):

Experimental work commenced and recruitment, screening and subject testing got fully underway.

REPORTABLE OUTCOMES (Feb-April):

See Key Research Accomplishments above

REPORTABLE OUTCOMES (April-July):

See Key Research Accomplishments above

REPORTABLE OUTCOMES (July-Oct):

In addition to new experimental testing and results provided above, our published prior work on locomotor mechanics and fatigue which was supported by the first round of funding on this award received considerable public attention in the last quarter. Several papers were published in 2009 and 2010 that involved comparison between intact-limb runner and double, lower-limb prosthetic running. These and related work on the mechanics of sprint running received extensive international press coverage in the last quarter in such widely read publications and wire services as the New York Times, The Economist, the Associated Press, ESPN, Yahoo Sports, CBS News, the BBC, and Discovery Channel Canada and hundreds of more specialized publications throughout the world.

CONCLUSIONS:

We have compiled a large portion of the data bases essential to further development and refinement of our stature-based model of the energy cost of walking and the development of a walking test of aerobic fitness. In both cases our data and modeling efforts incorporating these data have translated into successful algorithms that should prove useful, practical and valuable for military, clinical and general field usage. In the coming year we look forward to finalizing our data sets, pursuing intellectual property and publishing our results.

REFERENCES:

None

APPENDICES:

None